Ecological Indicators 95 (2018) 907–916

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Moving beyond description to explore the empirics of adaptation constraints

David Gawith[a], Ian Hodge[b,*]

[a] Department of Land Economy, University of Cambridge, United Kingdom
[b] Department of Land Economy, University of Cambridge, 21 Silver St, Cambridge CB3 9EP, United Kingdom

ARTICLE INFO

Keywords:
Climate change
Adaptation constraints
Adaptation barriers
Adaptation deficit
Adaptive capacity
Adaptation behaviour

ABSTRACT

The concept of adaptation constraints has become well known in the climate change literature. It describes impediments to the process of adaptation that could in principle be overcome but often are not. Many adaptation constraints have been identified and described in the literature across a wide range of contexts, and the importance of their influence on climate change adaptation is clear. However most studies have focussed on *describing* constraints rather than exploring their origins, processes, and possible impacts. As a consequence, it has been difficult to operationalise the concept to provide information meaningful to decision makers.

This study demonstrates an approach to estimating empirically the processes and the impacts of adaptation constraints, based on a case-study of farmers in New Zealand. It combines established social scientific methods to explore the processes underlying a range of adaptation constraints and estimate the impacts that these constraints may have. The approach can be used to explore further the social and economic impacts of adaptation constraints. This information can then be used to consider sub-optimal adaptation to climate change more fully, and paves the way for policy responses that are more conscious of the human elements of climate change adaptation.

1. Introduction

As limits to our ability to mitigate medium-term climate change and shortfalls in our actions to avoid long-term climate change become clearer (Rogelj et al., 2015, 2016), there has been a growing recognition of the importance of adaptation. Meinke et al. (2009, p.74) state that “Adaptation is rapidly emerging as one of the biggest global agenda items for this decade, and possibly the century”. While our understanding of the physical science of climate change has improved, and indicates a significant chance that warming will exceed 4 °C, Adger et al. (2009a, p. 20) point out that “… in effect, there is no science on how we are going to adapt to 4 °C warming”.

A small body of literature has identified considerable *potential* for human systems to adapt to climate change (Elliott et al., 2014; IPCC, 2014; Nelson et al., 2013). Some studies suggest that this potential may exceed the expected negative impacts of climate change, even in highly vulnerable communities (Gawith et al., 2015; Iglesias and Garrote, 2015; Nordhagen and Pascual, 2013).

As Adger and Barnett (2009) point out however, adaptive potential does not necessarily translate into adaptation. Despite increases in research and awareness, many studies report a lack of adaptive *action* (Mills et al., 2016; Berrang-Ford et al., 2011; Davidson, 2016; Lesnikowski et al., 2015; Burke and Emerick, 2016). Repetto (2009, p.20) points out that “to say that [we] *can* adapt to climate change does not imply that [we] *will* adapt” (emphasis in original). The difference between these two notions is fundamentally important, because underestimating the difficulties of adaptation risks forming unreasonably optimistic expectations about the costs of climate change.

Observations of the gap between adaptive potential and adaptive action demonstrate the existence of an ‘adaptation deficit’. The adaptation deficit is the gap between current and optimal levels of adaptation when optimal adaptation is considered to be that which delivers the “gross (or theoretically maximum) benefit of adaptation and risk management” (IPCC, 2012, p.265; Burton and May, 2004). In this sense, the adaptation deficit can be understood as inadequate adaptation to current climatic conditions (Burton, 2004; Burton and May, 2004), and the term can be closely linked to a broader ‘development deficit’ (World Bank, 2010; Hallegatte et al., 2016). Efforts to understand the adaptation deficit have focused on adaptation constraints – a term which has been used interchangeably with the terms ‘adaptation barrier’ and ‘adaptation obstacle’ in the literature (Fankhauser, 2017; Simões et al., 2017). This study adopts the definition of Eisenack et al. (2014, p. 868) who state that:

“[An adaptation constraint] is (1) an impediment (2) to specified

* Corresponding author.
E-mail addresses: gawith@gmail.com (D. Gawith), idh3@cam.ac.uk (I. Hodge).

https://doi.org/10.1016/j.ecolind.2018.08.022
Received 27 May 2018; Received in revised form 3 August 2018; Accepted 12 August 2018
Available online 06 September 2018
1470-160X/

adaptations (3) for specified actors in their given context that (4) arise from a condition or set of conditions. A [constraint] can be (5) valued differently by different actors, and (6) can, in principle, be reduced or overcome."

Adaptation constraints stem from the actors involved, their governance systems, and their environments and relate to behavioural, social, economic, and environmental characteristics (Biesbroek et al., 2013; Masud et al., 2017; Simões et al., 2017). Adger et al. (2009a, p.3) suggest that analyses that overlook factors such as adaptation constraints "may present a dangerously misleading understanding of the consequences of climate change". Despite this, adaptation constraints are often ignored in studies seeking to assess the economic impacts of climate change (Nolan et al., 2009; Gifford et al., 2011; Mendelsohn and Dinar, 2009).

While a large number of adaptation constraints have been identified in recent years, there remains what de Bruin and Dellink (2011, p.34) describe as "a significant gap in the literature regarding the effects of restrictions on adaptation". In their review of the adaptation constraints literature, Biesbroek et al. (2013, p.1119) found that a vast number of distinct constraints have been identified, but concluded that there is a need to move beyond the *identification* of constraints to assess their origins, processes, and possible impacts. While recent work by Herrmann and Guenther (2017), Burnham and Ma (2017), and Masud et al. (2017) has added empirical rigour to the identification of adaptation constraints, their methods stop short of estimating the impacts that these constraints may have.

Indeed, because of the lack of empirical depth, Biesbroek et al. (2015) have questioned the value of the concept of adaptation constraints. They argue that the linear, functionalist, and generally descriptive treatment of constraints has provided little insight useful for policy. De Bruin and Dellink (2011, p.42) acknowledge that "Understanding what adaptation restrictions are actually being faced or are likely to arise is an important issue that direly needs more attention."

This study aims to demonstrate a generalizable method for exploring the empirics of adaptation constraints. It uses qualitative and quantitative data from a case study of farm decision-makers in New Zealand to evaluate which constraints are likely to be important, how they manifest, and how large their impacts might be. The results of this work are presented in a way that could be used meaningfully in policy and model-based analysis of climate change adaptation.

2. Empirical methods

2.1. Focus

This study focusses on the constraints on adaptation in agriculture because of the vulnerability of the sector to climate change. While climate change is a global problem, its impacts vary at local scales and require local adaptive solutions. Therefore, this study focuses on adaptive responses in a single agricultural case study catchment in New Zealand called the Hikurangi catchment, shown in Fig. 1. The Hikurangi catchment is located in the Northland region and covers an area of approximately 84,000 ha. Of that total area, 41% is currently used for drystock farming, 38% for dairy farming, 9% for plantation forestry, and 1% for horticulture.

Approximately half of all farms in New Zealand are owner operated or owned in a single family trust (Nuthall, 2006; Brown et al., 2013). Owner operators were therefore the primary actors of concern in this study. Landlords, banks, private-sector extension services, and local authorities were also likely to be important actors in adaptation decision making, so their influence was also considered.

2.2. Empirical approach

The empirical assessment of adaptation constraints was designed to assess the relative impacts of adaptation constraints and to develop numerical preference functions to represent them in modelling and policy analysis. Given that the dominant models that explore the economic impacts of climate change use various forms of economic optimization (Mendelsohn and Dinar, 2009; Nolan et al., 2009), these preference functions were defined as quantitative deviations from a profit-maximising scenario. For example, a number of constraints are put forward as reductions in the likelihood that farmers will make a profit-maximising adjustment. Others are put forward as adjustments to the profit-maximising calculus whereby adjustment costs or time delays affect farmers' decisions.

Constraints were explored first in a review of existing literature about the constraints on agricultural adaptation to climate change. This informed the design of a mixed methodological approach to empirically assessing adaptation constraints. Semi-structured interviews were used to gain an understanding of farmers' attitudes, perceptions of risk, and how and why their adaptive behaviours might depart from profit maximisation. An extensive socioeconomic survey was used to assess whether the hypothesised constraints correlate with farmers' expressed adaptive propensities, and if so, how strong these correlations were. The qualitative findings were used to inform the construction of preference functions, a number of which were quantified using the results of the quantitative assessment. This structure is shown diagrammatically in the graphical abstract.

2.3. Survey approach

Surveys were used to understand the characteristics and variance of important farmer attributes, as well as to test the significance and strength of a range of adaptation constraints. In order to maximise the potential reach of survey questions, this study contributed to the design of, and took data from, an existing large-scale national longitudinal survey programme called the Survey of Rural Decision Makers (SRDM) (Brown et al., 2013; Brown, 2015). The 2015 SRDM collected data on a wide range of conditions and opinions relevant to rural land use and management (Brown, 2015; Brown and Roper, 2017). A suite of questions relating to expected changes in climate, challenges in accessing climate change information, expected changes in future land use and management practices, the perceived importance of profit, lifestyle, and environmental performance, past experiences of climate related stress, and the efficacy of institutions was developed and included specifically for this study.

The survey was designed and administered online. It was sent to 65,000 email addresses of farmers listed in the National Animal Identification and Tracing database (1831 responses), 1897 individuals who had previously responded to the 2013 SRDM (636 responses), and was advertised by a number of industry groups including Beef + Lamb New Zealand, the Farm Forestry Association, Federated Farmers, Horticulture New Zealand, the QEII Charitable Trust, and Rural Women (Brown et al., 2016). This garnered 2832 responses from commercial farm owners and farm managers. Due to space constraints in the survey, a randomly selected 25% (708) of the 2832 commercial respondents were asked questions about climate change relevant to this study.

Given the mixture of distribution techniques, it was not possible to determine an overall response rate. These techniques may be expected to bias the dataset towards farmers who use computers and email on a regular basis. Furthermore, given the major source of responses was a livestock database, the techniques also risked under representing non-pastoral agriculture. Despite these potential biases, the overall dataset was found to closely match population data from the 2012 census in terms of farmer age and industry (Brown and Roper, 2017).

2.4. Interview approach

Semi-structured interviews were used to explore the salience, origins, and processes of adaptation constraints. Interviews were designed

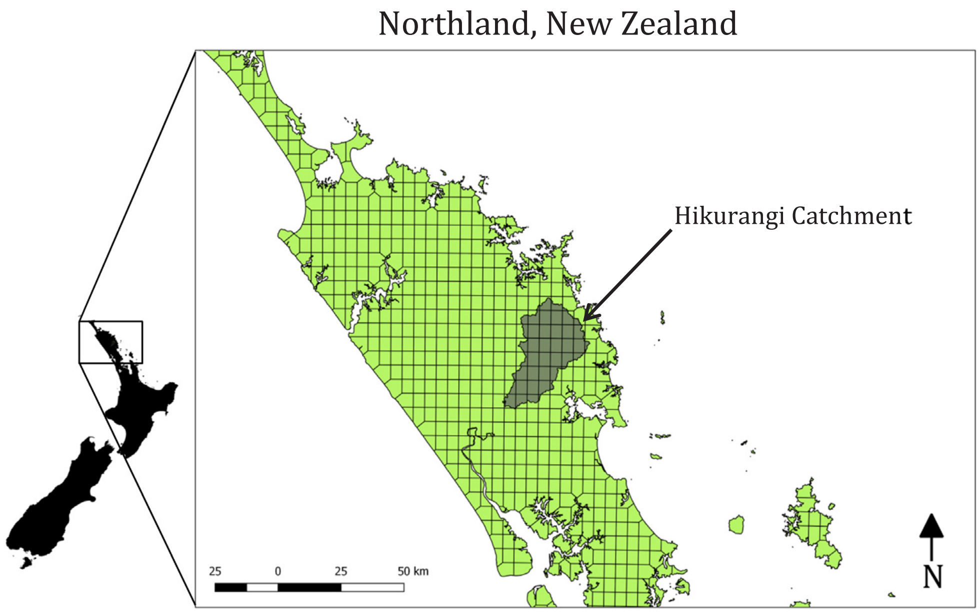

Fig. 1. Location of the Hikurangi catchment in Northland, New Zealand.

to explore issues and questions that arose from the socioeconomic survey, and were flexible to allow for the identification and exploration of new questions that arose during the interviews. The interview schedule began by questioning whether the farmers had made, or were intending to make changes to their land uses or management practices. The farmers were then asked whether there were (are) any specific challenges they faced (would face) when implementing these changes. Once farmers identified what they considered to be the most important challenges, henceforth understood to be adaptation constraints, the origins of, and processes driving these constraints were discussed. The final section of the interviews focused on a number of adaptation constraints which, by their nature, were unlikely to be identified by the farmers themselves. These included constraints relating to information, cognition, and perception of climate risk, as well as ideological and attitudinal inhibitions.

Interviewees were selected using a snowball-sampling strategy. Following Nelson et al. (2014), farmers were also asked to identify individuals, be they extension workers, land managers, financial service agents, local politicians or similar, whom they considered to be integral to the adaptation process (henceforth referred to as adaptation agents). Those identified were then also approached. Important findings of the initial farmer interviews were cross-checked with these adaptation agents to assess their robustness (Bradshaw and Stratford, 2010).

The sample of farmers in the qualitative research was intended to include a broad range of farmer types rather than ensure proportionality (Bradshaw and Stratford, 2010). A total of 38 individuals were interviewed across 32 separate interviews during the initial period of fieldwork. 32 interviewees were farmers, spanning a broad range of ages and farm sizes, and six were adaptation agents. All of the farmers interviewed were owner-operators, because this group was seen to have the most agency in adaptive decisions. Some farmers owned highly profitable portfolios of properties, while others were in the process of downscaling or exiting the industry because of a lack of economic turnover. One of the adaptation agents and seven of the farmers interviewed were female, while the rest of the interviewees were male. In order to safeguard the anonymity of the respondents, all of the survey responses are discussed in the masculine in this paper. Four farmers declined the invitation to partake in an interview, representing a response rate of 88%.

All interviews were audio-recorded and transcribed verbatim. The dialogue was then analysed for broad themes by coding responses using the qualitative analysis software NVivo, following the best practice recommendations of Cope (2016).

2.5. *Quantitative analysis of survey data*

The literature review and semi-structured interviews revealed a range of constraints that were likely to affect adaptation in the Hikurangi catchment. Of these possible constraints, those for which data were collected in the survey were analysed econometrically. This was done by constructing an index for adaptive propensity based on farmers' stated probability of changing the land use mix on their farms and their expectations of the extent of land use change under climate change. This adaptive propensity index was then regressed against indices for individual adaptation constraints. Formulation of these indices is described in the following section, while the regression method is described in Section 2.5.2.

2.5.1. *Indexing*

It was not possible to measure directly the adaptive propensity of farmers, nor many of the identified constraints used in this study. Multiple measures were therefore aggregated as indices, providing theoretical advantages over the use of a single indicator while focusing the interpretation on single metrics (Booysen, 2002; Brown et al., 2013).

The indicator variables used to form indices were selected based on findings from the literature review and the interviews. The interviews revealed a number of conditions underlying individual constraints, and where survey data on these conditions were available, these were added to the constraints' indices. The indicator variables comprising each of the indices used in this study are listed in Table 1.

The indicator variables were scaled using Linear Scaling Transformation (LST). In many of the indices, minimum and maximum values were either pre-defined (for example, as Likert scales), or simply taken as the minimum and maximum values recorded in the datasets. When this was not the case, judgements informed by assessment of the data were used to define extreme values. The LST calculation and the minimum and maximum values for each variable are shown in Table 1.

Weightings were not applied to the indicator variables used in this study because their relative importance was not knowable to any reasonable degree of confidence. Indices were calculated as the unweighted average of the relevant items (Brown et al., 2013). The results

Table 1
Description of the indicator variables, scaling and aggregation processes for each of the indices used.

Index	Indicator Variable	Variable Name	Data Type	LST Min	LST Max	LST Equation	Index Equation
Dependent variable	Likelihood of converting land use within two years	plan_convert	Likert	1	3	$LST = \frac{value-1}{2}$	Dependent Variable Index = ((LST plan_convert + LST cc_land_use_exp)/2)*100
	Expectation of land use change under climate change	cc_land_use_exp	Likert	0	10	$LST = \frac{value}{10}$	
Farmer Motivation and Aspiration	Ranking of the importance of financial performance	objective_fin	Likert	1	3	$LST = 1-\left(\frac{value-a}{2}\right)$	Aspiration index = ((LSTobjevtive_fin + LST age)/2)*100
	Age	age	Cardinal	21	85	$LST = 1-\left(\frac{value-21}{64}\right)$	
Behavioural Constraints	Risk tolerance	risk	Likert	0	10	$LST = \frac{value}{10}$	Behavioural Index = ((LSTrisk + LSTexperiment + LSTamong_first)/3)*100
	Preference to wait for others to experiment	experiment	Likert	0	10	$LST = 1-\left(\frac{value}{10}\right)$	
	Likelihood of being among first to try new practices	among_first	Likert	0	10	$LST = \frac{value}{10}$	
Perception of Climate Risk	Expectations for change in average temperature by 2050	cc_temp_exp	Binary	0	1	$LST = value$	Risk Perception index = ((LSTcc_temp_exp + LSTcc_rain_exp + LSTcc_drought_exp)/3)*100
	Expectations for change in average rainfall by 2050	cc_rain_exp	Binary	0	1	$LST = value$	
	Expectations for change in the prevalence of drought by 2050	cc_drought_exp	Binary	0	1	$LST = value$	
Disaster Experience	Impact of previous land use change on financial performance	luc_affect_fin	Likert	1	3	$LST = \frac{value-1}{2}$	Experience – Index = ((LSTluc_affect_fin + LSTluc_affect_env + LSTluc_affecr_life)/3)*100
	Impact of previous land use change on environmental performance	luc_affect_env	Likert	1	3	$LST = \frac{value-1}{2}$	
	Impact of previous land use change on lifestyle	luc_affect_life	Likert	1	3	$LST = \frac{value-1}{2}$	
Institutional Constraints and Governance	Effectiveness of regional councils in managing water	water_mgmt_councils	Likert	0	10	$LST = \frac{value}{10}$	Institutions Index = ((LST water_mgmt_councils + LST water_mgmt_farmers)/2)*100
	Effectiveness of local farmers in managing water	water_mgmt_farmers	Likert	0	10	$LST = \frac{value}{10}$	
Financial Constraints	Frequency with which a lack of finance was cited in decisions not to change	sum_financial_constraints	Sum of Binary	0	2	$LST = 1-\left(\frac{value}{2}\right)$	Financial Index = (LST sum_financial_constraints) *100
Scale Constraints	Total farm area	area	Cardinal	1	5000	$LST = \frac{value-1}{4999}$	Scale Index = ((LST area + LST total_stockUunits)/2)*100
	Total number of stock units	total_stock_units	Cardinal	1	15,000	$LST = \frac{value-1}{14999}$	
Perceived Self-efficacy	Frequency with which a lack of skills were cited in decisions not to change	sum_skills_constraints	Sum of Binary	0	2	$LST = 1-\left(\frac{value}{2}\right)$	Self-efficacy Index = ((LST aggregate skills constraint + LST cc_mgmt_exp + LST cc_mgmt_exp)/3)*100
	Expectation of management change under climate change	cc_mgmt_prac_exp	Likert	0	10	$LST = \frac{value}{10}$	
	Expectation of land use change under climate change	cc_land_use_exp	Likert	0	10	$LST = \frac{value}{10}$	

(*continued on next page*)

Table 1 (*continued*)

Index	Indicator Variable	Variable Name	Data Type	LST Min	LST Max	LST Equation	Index Equation
Technical Expertise	Frequency with which a lack of skills were cited in decisions not to change	sum_skills_constraints	Sum of Binary	0	2	$LST = 1 - \left(\frac{value}{2}\right)$	Expertise Index = ((LST sum_skills_constraints + LST sum_ag_training)/2)*100
	Agricultural training completed in the past	sum_ag_training	Sum of Binary	0	3	$LST = 1 - \left(\frac{value}{3}\right)$	
Agricultural Information Constraints	Lack of advice cited in decisions not to change	advice	Sum of Binary	0	2	$LST = 1 - \left(\frac{value}{2}\right)$	Information Index Ag. = ((LST demonstrate + LST advice)/2)*100
	Lack of demonstration cited in decisions not to change	demonstration	Sum of Binary	0	2	$LST = 1 - \left(\frac{value}{2}\right)$	
Climate Change Information Constraints	Ease of finding authoritative information on the impacts of climate change	cc_info_ease	Likert	0	10	$LST = \frac{value}{10}$	Information Index CC = ((LST cc_info_ease + LST temp_exp_consistency + LST precip_exp_consistency + LST drought_exp_consistency)/4)*100
	Consistency of farmer's temperature expectations with science	temp_exp_consistency	Binary	0	1	$LST = 1 - value$	
	Consistency of farmer's precipitation expectations with science	precip_exp_consistency	Binary	0	1	$LST = 1 - value$	
	Consistency of farmer's drought expectations with science	drought_exp_consistency	Binary	0	1	$LST = 1 - value$	

were multiplied by 100 to produce indices that range from 0 to100.

This approach yielded 11 independent adaptation constraint indices and an index for the dependent variable of land use change propensity. While 22 potentially relevant constraints were identified in the literature review, space limitations and difficulty investigating certain constraints meant that nine of these could not be assessed in the SRDM. Of the 13 constraints that could have been assessed using survey data, two indices provided too few data to be credibly regressed against the dependent variable. Those constraints unable to be assessed using survey data were still explored during the interviews, which yielded numerical estimates for nine *ad hoc* constraints.

2.5.2. Regression

Correlations between the adaptation constraint indices and the adaptive propensity index were quantified using regression. Because the dependent variable and many of the independent variables were either measured using truncated data or comprise indices that are truncated by definition, a Tobit regression model was used (Stock and Watson, 2015; Brown et al., 2016). Tobit regression models provide a method for assessing correlations in continuous variables that are truncated at certain values (Stock and Watson, 2015; Brown et al., 2016). In Tobit regression, the dependent variable is estimated by:

$$y_i^* = \boldsymbol{x}_i^{'}\boldsymbol{\beta} + u_i,\ u \sim N(0,\ \sigma^2)$$

Where y_i^* is a latent variable equal to the observed variable, y_i when the latent variable falls between the two cutoff points, which in this case are 0 and 100, such that:

$$y_i = \begin{cases} 100 & y_i^* \geq 100 \\ y_i^* & \text{if } 0 < y_i^* < 100 \\ 0 & \text{if } y_i^* \leq 0 \end{cases}$$

$\boldsymbol{x}$ is a vector of independent variables which in this case include the indices listed in Table 1. $\boldsymbol{u}$ is the error term, which is assumed to be normally distributed.

2.6. Qualitative validation

The findings of the empirical investigation were scrutinised by three experts in the agricultural economy of the Hikurangi catchment during a follow-up fieldwork period. They were asked to comment on whether they thought each constraint represented a real process, how well they thought the constraints were structured, and whether they thought the magnitudes of the constraints were reasonable. This provided further triangulation of the initial findings.

3. Results and discussion

While 22 distinct adaptation constraints were identified as potentially important in the literature, only those 15 adaptation constraints for which sufficient evidence was found in the empirical case-study are reported here. Eight of the preference functions were estimated in an *ad hoc* manner as heuristic behavioural rules based largely on the findings of the interview data, similar to the approaches of Bharwani et al. (2005) Huigen et al. (2006) and Heckbert et al. (2010). Six further constraints were estimated quasi-objectively using regression results.

The quantification of constraints provides indicators of their relative importance, allowing policymakers to focus attention on and respond to the constraints that are most likely to be harmful. The constraints proposed are greatly simplified approximations of highly complex phenomena. While specified numerically, most are not intended to be applied deterministically. Their values should be expected to vary based on heterogeneous characteristics found among farmers. Many of the proposed preference functions are designed to include this heterogeneity. Each constraint should be judged by whether it provides a more plausible approximation of adaptive behaviour than would the

Table 2
Tobit regression results for 11 adaptation constraint indices and a binary variable for land use.

Dependent Variables	Coefficient	Standard Error	t	P > |t|	95% Confidence Interval	
Farmer Motivation and Aspiration	0.00	0.04	−0.04	0.97	−0.09	0.09
Behavioural Constraints	0.24	0.06	3.91	0.00	0.12	0.36
Perception of Climate Change Risk	0.16	0.12	1.36	0.18	−0.07	0.40
Institutional Constraints and Governance	0.04	0.05	0.77	0.44	−0.06	0.15
Scale Constraints	0.08	0.06	1.24	0.22	−0.04	0.19
Financial Constraints	0.01	0.04	0.14	0.89	−0.08	0.09
Perceived Self-Efficacy	0.74	0.09	7.96	0.00	0.56	0.92
Technical Expertise	0.20	0.07	2.78	0.01	0.06	0.34
Agricultural Information Constraints	−0.16	0.08	−1.89	0.06	−0.33	0.01
Disaster Experience	0.15	0.06	2.42	0.02	0.03	0.27
Climate Change Information Constraints	−0.20	0.15	−1.37	0.17	−0.49	0.09
Land Use Dairy	−7.78	2.27	−3.43	0.00	−12.24	−3.33

6 left-censored observations at DV ≤ 0.
397 uncensored observations.
0 right-censored observations.

assumption that farmers work to maximise profit.

3.1. Regression results

Five of the 11 indices tested in the Tobit model were found to have statistically significant correlations with adaptive propensity. The results of the regression are shown in Table 2. Four of these constraints show the expected positive correlations with the coefficients indicating the relationship between a one point change in the constraint and the adaptive propensity index. Whether or not farmers practiced dairying was also included in the model as a binary independent variable.

In Tobit models, the underlying latent variable is unobservable, therefore there are no strictly formal measures of model fit (Hoetker, 2007). For this reason pseudo measures of model fit are not reported in this study.

3.2. Quasi-objective constraints

The following six constraints were structured based on the semi-structured interviews and quantified based on the regression results.

3.2.1. Behavioural constraints

Of the 33 farmers interviewed, seven demonstrated potential behavioural constraints during their interviews. These instances were narrowly focused on an aversion to management risks. Behavioural constraints were, therefore, assessed using data on risk tolerance collected in the SRDM to form an index which was found to significantly correlate with adaptive propensity. Based on this evidence, farmers' adaptive decisions should be understood to be constrained by risk aversion. Specifically, each point below 100 that farmers scored on this index reduced their adaptive propensity by 0.24%.

3.2.2. Disaster experience

Interviews with farmers in the Hikurangi catchment corroborated previous findings that past exposure to extreme weather events increases adaptive propensity (Tompkins, 2005; Niles et al., 2013; Mills et al., 2016). Farmers' ages and the lengths of time they had spent farming in the area were the main determinants of disaster experience. Based on this, data on the age of farmers and the length of their experience in farming were used to form an index that was found to significantly correlate with adaptive propensity. Adaptation should thus be understood to be constrained when farmers lack experience of climate related disasters. Specifically, each point below 100 that farmers scored on the Disaster Experience index reduced their adaptive propensities by 0.15%.

3.2.3. Perceived self-efficacy

Interviews with farmers demonstrated perceived self-efficacy to be lower than considered to be plausible (Brown et al., 2013; Wolf et al., 2009; Burnham and Ma, 2017). A number of farmers held fatalistic attitudes believing that there was nothing they could do to change the impact that climate change might have on their businesses. For example, one horticulturalist reflected on crop damage sustained during a wind storm, saying "Look, there's absolutely nothing I could have done about it." Despite this, later in the same interview he acknowledged the difference that well-structured shelter-belts can make. Based on this evidence, data on cited lack of skills and expectations of personal adaptive responses were used to form an index for perceived self-efficacy, which was found to correlate significantly with adaptive propensity. Farmers with lower perceived self-efficacy can therefore be expected to be less likely to adapt to climate change. Specifically, each point below 100 that farmers scored on the adaptive propensity index reduced their adaptive propensities by 0.74%.

3.2.4. Technical expertise

The costs of developing technical expertise in new fields were frequently mentioned by the farmers interviewed. Reflecting on the management changes required to convert land from dairy to drystock, a representative of the dairy industry said "… given my experience, it has been challenging for them. I'm gauging that from trying different crops and the result of the crop… there's not a lot in that initial uptake that has true success." Data on agricultural training and perceived lack of expertise were used to form an index of technical expertise, which was found to significantly correlate with adaptive propensity. Based on this evidence, farmers with lower levels of technical expertise should be understood to be less adaptive where each point below 100 that farmers scored on the Technical Expertise index reduced their adaptive propensity by 0.2%.

3.2.5. Information constraints

Among the farmers interviewed, many highlighted the costs involved in both accessing and processing information, and a number questioned the quality and impartiality of the information available. In light of this, data on whether farmers cited a lack of advice and demonstration as a constraint on their land use and management decisions were used to form an index of agricultural information constraints. Surprisingly, this was found to correlate positively with adaptive propensity. Specifically, each point below 100 on the index was associated with a 0.16% *increase* in adaptive propensity. This relationship conflicted with the expectations of two of the experts interviewed in the qualitative validation exercise. One commented "I would have thought that being more informed gives more confidence" while the other suggested that the information constraints must be dominated by other

subjective factors. In light of uncertainty about the reasoning behind this, no preference function is proposed for this constraint. It does, however, demonstrate the value of the iterative exploration of constraints undertaken in this study, and highlights the fact that isolated methods may provide spurious results.

3.2.6. Path dependence

Among the farmers interviewed, the large capital and infrastructure investments that had been needed to develop dairy farms were commonly cited as reasons to continue dairying, despite the fact that they were sunk costs. For example, one dairy farmer who thought that horticulture could be more profitable on part of his land justified remaining a full dairy operation by saying "I guess all the capital infrastructure and things have been put there to milk cows". Responses like this suggested that the decision to develop a dairy farm may be particularly path dependent given the large investments required. This inference was tested in the regression model described in Section 3.1 using a binary variable for practicing dairy farming. This was found to have a significant negative correlation with adaptive propensity such that dairy farmers had 7.78% lower propensities to change land use, on average.

3.3. Ad hoc constraints

Nine further constraints were specified based on the results of the semi-structured interviews, informed by, and in some cases cross-checked with the literature. As with the quasi-objective constraints, they are presented as numerical preference functions that could be used in modelling and policy analysis. The assessments are intentionally conservative in order to avoid exaggerating their importance, representing the lowest plausible impact each constraint might have. Again, each constraint should be judged by whether it provides a more reasonable approximation of adaptive behaviour than the assumption that farmers work to perfectly maximise profit.

Three constraints, namely gender, tenure, and ideological constraints, were identified in the literature but found little empirical support in the Hikurangi catchment. There was no mention of systematic difference in access to adaptation opportunities between genders. While eight of the 38 interviewees were female, it is possible that female respondents avoided mentioning gender inequality because the interviewer was male. The responses may have differed were the interviewer female, however this was not tested. Tenure was only mentioned twice during the interviews, both times by the same interviewee. There were only two clear instances of ideological constraints during the interviews. One farmer showed a strong ideological resistance to expert advice, saying "It really gripes me when people come along and tell you 'all the experts [have written] a paper [about] what the farmers should do. God, all these bureaucrats that tell the farmers how to farm". The only other farmer who showed ideological constraints was far more circumspect, responding to a question about climate change by saying "I just wonder if it's a hype… I don't know, I'm probably wrong." Beyond these two very different examples, there was a notable lack of fixed ideologies among the farmers interviewed, contrasting with the emphasis in the literature (Milfont, 2012; Gifford et al., 2011). It is possible that this reflects sampling bias and that those interviewed were among the more open-minded farmers in the region. However because of the limited empirical evidence, these three constraints were discarded.

3.3.1. Farmer motivation and aspiration

Farmer motivation and aspiration was the single most cited category of adaptation constraint across the interviews of which lifestyle, profit, and environmental protection were the three most commonly cited motivations, garnering 154, 52, and 23 references, respectively.

Drystock farming was generally seen as the 'easiest' of the main land uses, and one that provides a good lifestyle. One dairy farmer admitted "I think most dairy farmers want to be beef farmers". One avocado orchardist explained his preference for beef farming over growing avocados, saying "it's probably going to be less work". When asked what he would do if all land uses produced the same return, one silviculturalist replied "… cattle, I'd just go cattle. Straight cattle."

Based on this evidence, the potential for considering farmers to hold a 10% preference for drystock farming over other land uses was discussed with three experts during qualitative validation. One of the experts stressed the importance of age in determining lifestyle as a motivator, pointing out that farmers early in their career are likely to be highly motivated by profit, while older farmers may be more motivated by lifestyle. Two of the experts thought that setting this preference at 10% was overly conservative. In light of these responses, a preference for drystock farming should be scaled according to age, and could take a minimum value of 0 for the youngest farmers, and a maximum of 30% for the oldest farmers.

Concern about the environmental impacts of farming differed greatly between farmers. While 65% of the farmers interviewed did not mention environmental protection as a motivation, of those who did, some mentioned incurring costs over and above regulatory compliance, or forfeiting potential profits in order to improve the environment of their farm. Notably, concern for the environment was strongly held by Māori, the indigenous peoples of New Zealand. One farmer, who was given the title "Kaitiakitanga" (guardian) by the local iwi (tribe) said that regardless of how much extra profit it could return, he would not consider switching to intensive dairying because of the importance he placed on his environmental reputation, particularly in the eyes of local Maori. He further explained "It's probably like a religion…"

This evidence suggests that Māori farmers are less likely to consider changes to land use that negatively affect the local environment. The potential for considering Māori farmers to be 10% less likely to accept changes to more intensive land uses was therefore discussed with three experts during qualitative validation. Two of the experts pointed out that it was not only Māori farmers who held the value of Kaitiakitanga. One of the experts estimated that the concept was held by between 20% and 25% of farmers in his experience. Another expert suggested the preference was likely to be between 15% and 20%. A conservative approach could therefore assume that 20% of farmers are 15% less likely to adopt more environmentally damaging land uses or practices.

3.3.2. Cultural constraints

A cultural attachment to occupation was clear in the interviews. For example, when asked about why he chose to run dairy cows on his land, one farmer responded: "first and foremost I'm a dairy farmer…" This justification was echoed by another farmer who bought a beef farm and converted it to dairy. Asked why he changed land use he explained "We were dairy farmers, not beef farmers". Based on this evidence, potential existence of a 10% preference for remaining in the same industry was discussed with the three experts during quantitative validation. All three thought that this preference existed and that understanding it to influence adaptive propensity by 10% would be reasonable.

3.3.3. Social information

Social networks have been found to strongly influence the dispersal of information and innovation that contribute to adaptation (Adger, 2003; Wolf et al., 2009). The interviews suggested that the information provided by social networks is often inaccurate. According to one agricultural contractor, farmers may be particularly inclined to report inaccurate costs if "they got ripped off and they don't want to tell anyone it cost them $100,000 when it should have been $50,000". Another dairy farmer gave more strategic reasons for withholding information, saying "I glean information from all sorts of people, but I don't willingly give those system changes that I am tinkering with to my neighbours… because they are my competitors…" Based on this evidence, the potential existence of variation with a standard deviation of 10% in the information on profit gathered through social networks was

discussed with three experts during qualitative validation. While all three experts agreed that this would be reasonable, one pointed out that social information constraints were likely to be less apparent among dairy farmers because of a range of information sharing platforms in the industry. Based on this evidence, with the exception of the dairy industry, the information famers gather from social networks can be expected to vary with a standard deviation of 10% around its true value. This variation will affect farmers' abilities to maximise profits under changing conditions.

3.3.4. Institutional constraints and governance

Shortfalls in the effectiveness of institutions in aiding farmers to maximise their returns under changing conditions were the fourth most frequently cited constraints, appearing 106 times across 17 of the 32 interviews. A number of interviewees made it clear that there may be regulatory limits to land use change in the future. One forester mentioned that under the Resource Management Act 1991 "The Northland Regional Council… had the whole of Northland classed as… high value natural heritage… Basically it was protected". Based on this evidence, the prohibition of change in areas covered by native forest was discussed with the three experts during qualitative validation. One of the experts pointed out that the regulatory limits were not rigid. According to him, "not all native forest is a protected natural area, and not all protected natural areas are protected under the district plan anyway… and then having said that… some farmers ignore it when it is…" Another expert provided counter evidence suggesting that it would be extremely hard to clear native bush, and cited the district council rules (Whangarei District Council, 2017) which prohibit clearance of native vegetation unless:

a) It is the removal of trees that are a danger to human life or existing structures; or
b) Clearance is for a new fence where the purpose of the fence is to exclude stock and/or pests from the area; or
c) It is beneath a canopy of a production forest; or
d) The removal of a tree or trees, or the gathering of plant matter is in accordance with Māori custom and values.

On the balance of this evidence, it would be reasonable to expect areas of the catchment classed as native forest to be 95% less likely to change to a productive land use. This level allows for clearing of native forest in exceptional circumstances, and a small degree of non-compliance.

3.3.5. Response lags

A number of the farmers interviewed highlighted both the existence and the necessity of response lags, pointing out that the speed at which changes are made affects the quality of the finished system. There was a clear link between response lags and financial constraints in the interviewees' responses. For example, asked why completing a conversion from beef to dairy had taken almost a decade, one farmer explained "We had to chip away at it slowly just as we've had the money…"

Response lags differed by specific land use changes. Discussing the time it takes to convert from drystock to dairy farming, one seed supplier explained "You cannot get pasture that's been running beef into dairy pasture immediately… you can pour a ton of fertiliser to the acre and it won't achieve it… Building fertility in the ground and improving it, it's just time really… We aim [to] get around the farm in about eight years. If we can do that, we are right up with probably the most or as much new grass growing as we can handle." Based on this evidence, any benefits of converting to dairy from drystock should be understood to take eight years to manifest, on average. Variations in this delay should be expected based on farmers' financial positions, with wealthier farmers reaching full profitability more rapidly than those who are more financially constrained.

Regarding the response lags when converting to horticulture, one farmer explained: "You've got to plant the shelter and put the drainage in and the irrigation and then plant the trees. Then sit and wait for three years or four years or whatever…" Any benefits of establishing an orchard should therefore be understood to take between three and five years to manifest, depending on the farmers' financial positions.

One seed supplier who had experience converting a felled forestry block to pasture explained "it's probably taken five to eight years to actually get productive pastures…" Any benefits of converting from forestry to pasture should therefore be understood to take between five and eight years to manifest depending on the farmers' financial positions. The same seed supplier had been involved with the conversion of an orchard to pasture, noting that this was a much quicker job and the pasture was productive within three years. It would therefore be reasonable to assume between two and four years' lost production for farmers undertaking this conversion, depending on their financial positions.

3.3.6. Climate change information constraints

Among those interviewed, only three farmers said that they gathered information on how climate change might affect agricultural conditions in their region. Of those three, two said that this information had little impact on their decisions. A much larger proportion of interviewees were sceptical about whether climate change projections are credible, and a small number seem convinced that they are not.

This suggests that the vast majority of farmers are likely to respond only to *observed* climate. Given that climate is defined as an average of conditions over 30 years, changes in response to observed climate are likely to substantially lag changes in conditions. Using the simplifying assumption that changes will be linear, the moving 30-year average of *observed* climate would trail the current conditions by 15 years. Therefore, it would be reasonable to expect that farmers who misidentify the direction of projected climate change will be less likely to change land use in response to changing climatic conditions until these conditions have prevailed for 15 years. Beyond this length of time, even sceptical farmers could be expected to observe climate change regardless of their knowledge of or views about climate change projections.

3.3.7. Financial constraints

Financial constraints were the second most cited constraints among farmers in the Hikurangi catchment, appearing 163 times across 29 of the 32 interviews. The costs of a number of land use changes were discussed in detail.

The costs of changing land use from drystock to dairy were seen to be substantial because of the large amount of new infrastructure needed to develop a dairy farm, and the work required to improve pasture productivity. One farmer who farmed beef on land that he admitted would be highly suitable for dairy explained "it [would] costs us roughly over two million dollars to convert it, by the time you build the cow shed and buy the shares. You'd have to put another house on it…" Based on this estimate of $2,000,000 for a 347 ha property, the costs of changing land use from drystock to dairy would be $5764 per hectare.

The costs of planting or removing production forestry were also seen to be considerable. A representative for a seed supply company explained that when establishing forestry "… you have ongoing costs… It's basically blanket sprayed and then the plants are released. They quite often have a fungicide put over the top of the trees and a fertiliser in the first sort of 12– 18 months." Regarding conversion to pasture from forestry, a representative of the dairy industry explained "you've got to get rid of the stumps… Also you'd have to do your fencing, your water reticulation, fertiliser." Using the Farm Financial Budget Manual (Askin and Askin, 2014), the costs of planting forestry could be estimated as $1575 per hectare, while the costs of converting forested land to pasture could be estimated as $3356 per hectare.

The costs of converting between horticulture and pasture are also likely to be significant. One industry representative who had been involved in a conversion from horticulture to pasture reflected that it had

been "… a big job, removing all the pergola-type structures and taking all the posts out… you've also got the different use of chemicals because you have residual strips under your crops… It does affect pasture for a while because they are designed not to let grasses and things invade." In total, he estimated that the conversion from horticulture into pasture cost around $3000 per hectare. In the other direction, one famer who had been considering establishing kiwifruit on his land had a quote for $86,634 per hectare, of which the licence to sell kiwifruit commercially accounted for roughly half.

In light of this evidence, the potential for assuming that farmers annualise these costs over a 25 year planning horizon and include them in their decision making was discussed with three experts during qualitative validation. While they all agreed that the costs of each specific land use change were set at reasonable levels, one of the experts thought that these costs should be annualised over ten to 15 years, explaining "I think 25's probably quite a long way out. Maybe too far out…" In light of this, each of the conversion costs described above could be annualised over 15 years. This annualised cost can be assumed to influence farmers' estimates of the potential profits from each land use.

In addition to these individual financial considerations, many farmers pointed out that the lack of cash flow while the trees are growing was a major barrier to considering forestry as a land use. One dairy farmer with experience in forestry explained "… the return is not 'til the end so you've got to have some income for all those years…" One dairy farmer admitted that he would prefer to remain in dairy even if forestry were guaranteed to provide 10% more profit over the forest lifecycle. A number of farmers pointed out that because of the lack of cash flow, a secondary form of income would be necessary in order for forestry to become a viable land use option.

The potential for considering forestry impossible for farmers who earn less than 10% of their income from sources other than agriculture was discussed with three experts during qualitative validation. All three thought that farmers would need far more than 10% of their income from outside sources to make forestry a viable land use. In light of these responses, it might be reasonable to expect farmers to need 50% of their income to come from off-farm sources to be able to be able to manage the impacts that a change to forestry would have on farm cash-flow.

3.3.8. Labour

Constraints on the amount of labour available were mentioned 66 times across 17 of the 32 interviews. A number of farmers suggested that skills and training were lacking among many in the labour force. For example, in the words of one farmer: "It's actually not that easy to get skilled people. It's not a job for dummies." With this in mind, the potential for assuming that the rate of expansion of the area of each land use would be limited to 4% per year was discussed with three experts during qualitative validation. One expert cited greater flexibility in the labour market, and suggested that expansion may be able to occur at up to 6% per year. The maximum rate of expansion in any land use in any one year could therefore be expected to be limited to roughly 6%.

4. Conclusions

The methods employed in this study demonstrate techniques for exploring the empirics of adaptation constraints, however important uncertainties remain. The data collected in the surveys and interviews captured only stated preferences. There is considerable scope to extend these methods using experimental economics and behavioural science to explore revealed preferences and behaviours. Furthermore, the indicator variables put forward in Section 2.5.1 are subjective because our understanding of complex social phenomena, and particularly how they interact, is imperfect and so is any attempt to collect data on them (Booysen, 2002; Alkire and Foster, 2011). The *ad hoc* constraints put forward in Section 3.3 are largely based on conservative, subjective estimates of the impacts each might have. The reviews of these estimates provided by experts may provide extra evidence that they do, indeed, provide reasonable descriptions of real phenomena. However there remain substantial uncertainties about their true values. In considering these uncertainties, each preference function should be judged by whether it provides a more reasonable approximation of adaptive behaviour than the assumption that farmers work to perfectly maximise profit. We argue that each of the constraints described here does improve on this assumption.

The methods presented here are able to account for a diverse range of constraints and provide the foundations for comparing their impacts quantitatively. This study demonstrates that the origins and processes of adaptation constraints can be explored using semi-structured interviews. The influence that some of these constraints may have can be tested quasi-objectively through the econometric analysis of survey data. The integration of behavioural and microeconomic theories that are well established in the literature with these social scientific methods allows for the triangulation of empirical insights. The qualitative validation of initial results provides further cross-checking of interpretation. This combination of well-established methods could be replicated to estimate the impacts of adaptation constraints in many different agricultural contexts. It might also be adjusted to explore adaptation constraints in other sectors.

The preference functions proposed here can and should be used to temper our model-based estimates of the economics of adaptation to climate change. They allow for an exploration of climate change adaptation that is more conscious of the constraints faced by individual business owners. Information about the workings and influences of individual constraints may also allow analyses to explore policies for alleviating constraints that are seen as harmful.

In aggregate, the adaptation challenges described in this paper contrast with what Adger and Barnett (2009, p.2804) point out is "a widespread belief that adaptation will be smooth, cheap, and easy to implement". In reality, adaptation is likely to entail substantial costs, both monetary and relating to non-monetised values, and may require wholesale transformations, some of which will be painful and risky. This paper demonstrates that the processes and influences of many of these challenges can be credibly estimated. We argue that it is no longer sufficient to ignore them when assessing the economics of climate change adaptation or designing adaptation policies.

Acknowledgements

This work was supported by the Woolf Fisher Trust and the Cambridge Commonwealth, European and International Trust, in the form of a Woolf Fisher Scholarship (2014). These sponsors had no involvement in the study design; in the collection, analysis and interpretation of data; in the writing of the report; or the decision to submit the article for publication.

References

Adger, W.N., 2003. Social capital, collective action, and adaptation to climate change. Econ. Geogr. 79 (4), 387–404.
Adger, W.N., Barnett, J., 2009. Four reasons for concern about adaptation to climate change. Environ. Plann. A 41 (12), 2800–2805.
Adger, W.N., Lorenzoni, I., O'Brien, K.O., 2009. Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press, Cambridge, United Kingdom and New York, USA.
Alkire, S., Foster, J., 2011. Counting and multidimensional poverty measurement. J. Public Econ. 95 (7–8), 476–487.
Askin, D., Askin, V., 2014. Farm financial Budget Manual. Lincoln University, Lincoln, New Zealand.
Berrang-Ford, L., Ford, J.D., Paterson, J., 2011. Are we adapting to climate change? Global Environ. Change 21 (1), 25–33.
Bharwani, S., Bithell, M., Downing, T.E., New, M., Washington, R., Ziervogel, G., 2005. Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. Philos. Trans. R. Soc. B: Biol. Sci. 360 (1463), 2183–2194.
Biesbroek, R., Dupuis, J., Jordan, A., Wellstead, A., Howlett, M., Cairney, P., Rayner, J.,

Davidson, D., 2015. Opening up the black box of adaptation decision-making. [Correspondence]. Nat. Clim. Change 5 (6), 493–494.
Biesbroek, G.R., Klostermann, J.M., Termeer, C.A.M., Kabat, P., 2013. On the nature of barriers to climate change adaptation. Reg. Environ. Change 13 (5), 1119–1129.
Booysen, F., 2002. An overview and evaluation of composite indices of development. Soc. Indic. Res. 59 (2), 115–151.
Bradshaw, M., Stratford, E., 2010. Qualitative research design and rigour. In: Hay, I. (Ed.), Qualitative Research Methods in Human Geography, third ed. Oxford University Press, Oxford, U.K..
Brown, P., 2015. Survey of Rural Decision Makers. Retrieved 7 February 2017, from < http://www.landcareresearch.co.nz/srdm2015 > .
Brown, P., Wright, W., Fernandez, M., Dawson, J., Roper, S., Robertson, T., 2016. Survey of Rural Decision Makers: Understanding decision makers in primary industry. Landcare Research Policy Brief 17. Auckland, New Zealand.
Brown, P., Roper, S., 2017. Innovation and networks in New Zealand farming. Aust. J. Agric. Resour. Econ. 61 (3), 422–442.
Brown, P., Small, B., Morgan, F., Lynch, C., Burton, R., Montes de Oca Munguia, O., Brown, M., 2013. Survey of Rural Decision Makers in Canterbury, Southland and Waikato: Final Report for the Ministry for the Environment. Wellington, New Zealand.
Burke, M., Emerick, K., 2016. Adaptation to Climate Change: Evidence from US Agriculture. Am. Econ. J.: Econ. Policy 8 (3), 106–140.
Burnham, M., Ma, Z., 2017. Climate change adaptation: factors influencing Chinese smallholder farmers' perceived self-efficacy and adaptation intent. Reg. Environ. Change 17 (1), 171–186.
Burton, I., 2004. Climate Change and the Adaptation Deficit. Occasional Paper 1. Meteorological Service of Canada, Environment Canada.
Burton, I., May, E., 2004. The adaptation deficit in water resource management. IDS Bull. Clim. Change Dev. 35, 3.
Cope, M., 2016. Organizing and Analyzing Qualitative Data. In: Hay, I. (Ed.), Qualitative Research Methods in Human Geography, fourth ed. Oxford University Press, Ontario, Canada.
Davidson, D., 2016. Gaps in agricultural climate adaptation research. [Commentary]. *Nature*. Clim. Change 6 (5), 433–435.
de Bruin, K.C., Dellink, R.B., 2011. How harmful are restrictions on adapting to climate change? Global Environ. Change 21 (1), 34–45.
Eisenack, K., Moser, S.C., Hoffmann, E., Klein, R.J.T., Oberlack, C., Pechan, A., Rotter, M., Termeer, C.J.A.M., 2014. Explaining and overcoming barriers to climate change adaptation. [Perspective]. Nat. Clim. Change 4 (10), 867–872.
Elliott, J., Deryng, D., Müller, C., Frieler, K., Konzmann, M., Gerten, D., Glotter, M., Flörke, M., Wada, Y., Best, N., Eisner, S., Fekete, B.M., Folberth, C., Foster, I., Gosling, S.N., Haddeland, I., Khabarov, N., Ludwig, F., Masaki, Y., Olin, S., Rosenzweig, C., Ruane, A.C., Satoh, Y., Schmid, E., Stacke, T., Tang, Q., Wisser, D., 2014. Constraints and potentials of future irrigation water availability on agricultural production under climate change. Proc. Natl. Acad. Sci. 111 (9), 3239–3244.
Fankhauser, S., 2017. Adaptation to climate change. Annu. Rev. Resour. Econ. 9 (1), 209–230.
Gawith, D., Hill, D., Kingston, D., 2015. Determinants of vulnerability to the hydrological effects of climate change in rural communities: evidence from Nepal. Clim. Dev. 1–16.
Gifford, R., Kormos, C., McIntyre, A., 2011. Behavioral dimensions of climate change: drivers, responses, barriers, and interventions. Wiley Interdiscip. Rev. Clim. Change 2 (6), 801–827.
Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., Vogt-Schilb, A., 2016. Shock Waves : Managing the Impacts of Climate Change on Poverty Climate Change and Development. World Bank, Washington, DC.
Heckbert, S., Baynes, T., Reeson, A., 2010. Agent-based modeling in ecological economics. Ann. N.Y. Acad. Sci. 1185 (1), 39–53.
Herrmann, J., Guenther, E., 2017. Exploring a scale of organizational barriers for enterprises'Climate change adaptation strategies. J. Clean. Prod. 160, 38–49.
Hoetker, G., 2007. The use of logit and probit models in strategic management research: critical issues. Strat. Manage. J. 28 (4), 331–343.
Huigen, M.G.A., Overmars, K.P., de Groot, W.T., 2006. Multiactor modeling of settling decisions and behavior in the San Mariano Watershed, the Philippines: a first application with the MameLuke Framework. Ecol. Soc. 11 (2).
Iglesias, A., Garrote, L., 2015. Adaptation strategies for agricultural water management under climate change in Europe. Agric. Water Manage. 155, 113–124.
IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. In: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. 582 Cambridge University Press, Cambridge, UK, and New York, NY, USA.
IPCC, 2014. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, pp. 1–32 Summary for Policymakers.
Lesnikowski, A., Ford, J., Biesbroek, R., Berrang-Ford, L., Heymann, S.J., 2015. National-level progress on adaptation. Nat. Clim. Change 6, 261.
Masud, M.M., Azam, M.N., Mohiuddin, M., Banna, H., Akhtar, R., Alam, A.S.A.F., Begum, H., 2017. Adaptation barriers and strategies towards climate change: challenges in the agricultural sector. J. Cleaner Prod. 156, 698–706.
Meinke, H., Howden, S.M., Struik, P.C., Nelson, R., Rodriguez, D., Chapman, S.C., 2009. Adaptation science for agriculture and natural resource management; urgency and theoretical basis. Curr. Opin. Environ. Sustainability 1 (1), 69–76.
Mendelsohn, R., Dinar, A., 2009. Climate Change and Agriculture. Edward Elgar Publishing Limited, Cheltenham, UK.
Milfont, T.L., 2012. The interplay between knowledge, perceived efficacy, and concern about global warming and climate change: a one-year longitudinal study. Risk Anal. 32, 1003–1020.
Mills, M., Mutafoglu, K., Adams, V.M., Archibald, C., Bell, J., Leon, J.X., 2016. Perceived and projected flood risk and adaptation in coastal Southeast Queensland, Australia. Clim. Change 136 (3), 523–537.
Nelson, K., Brummel, R., Jordan, N., Manson, S., 2014. Social networks in complex human and natural systems: the case of rotational grazing, weak ties, and eastern US dairy landscapes. Agric. Hum. Values 31 (2), 245–259.
Nelson, G.C., Valin, H., Sands, R.D., Havlík, P., Ahammad, H., Deryng, D., Elliott, J., Fujimori, S., Hasegawa, T., Heyhoe, E., Kyle, P., Von Lampe, M., Lotze-Campen, H., Mason d'Croz, D., van Meijl, H., van der Mensbrugghe, D., Müller, C., Popp, A., Robertson, R., Robinson, S., Schmid, E., Schmitz, C., Tabeau, A., Willenbockel, D., 2013. Climate change effects on agriculture: Economic responses to biophysical shocks. Proc. Natl. Acad. Sci.
Niles, M.T., Lubell, M., Haden, V.R., 2013. Perceptions and responses to climate policy risks among California farmers. Global Environ. Change 23 (6), 1752–1760.
Nolan, J., Parker, D., Van Kooten, G.C., Berger, T., 2009. An overview of computational modeling in agricultural and resource economics. Can. J. Agric. Econ./Revue canadienne d'agroeconomie 57 (4), 417–429.
Nordhagen, S., Pascual, U., 2013. The impact of climate shocks on seed purchase decisions in Malawi: implications for climate change adaptation. World Dev. 43, 238–251.
Nuthall, P.L., 2006. Determining the important management skill competencies: the case of family farm business in New Zealand. Agric. Syst. 88 (2–3), 429–450.
Repetto, R., 2009. The Climate Crisis and the Adaptation Myth. Working Paper Number 13. Yale University, Yale School of Forestry & Environmental Studies , New Haven, CT.
Rogelj, J., Luderer, G., Pietzcker, R.C., Kriegler, E., Schaeffer, M., Krey, V., Riahi, K., 2015. Energy system transformations for limiting end-of-century warming to below 1.5 [deg]C. [Perspective]. Nat. Clim. Change 5 (6), 519–527.
Rogelj, J., den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K., Meinshausen, M., 2016. Paris agreement climate proposals need a boost to keep warming well below °C. [Perspective]. Nature 534 (7609), 631–639.
Simões, E., de Sousa Junior, W.C., de Freitas, D.M., Mills, M., Iwama, A.Y., Gonçalves, I., Olivato, D., Fidelman, P., 2017. Barriers and opportunities for adapting to climate change on the North Coast of São Paulo, Brazil. Reg. Environ. Change 17 (6), 1739–1750.
Stock, J.H., Watson, M.W., 2015. Introduction to Econometrics, Global ed. Pearson Education Limited, Harlow, England.
Tompkins, E.L., 2005. Planning for climate change in small islands: Insights from national hurricane preparedness in the Cayman Islands. Global Environ. Change 15 (2), 139–149.
Whangarei District Council, 2017. Whangarei District Plan. (retrieved 27.02. 17).
Wolf, J., Lorenzoni, I., Few, R., Abrahamson, V., Raine, R., 2009. Conceptual and practical barriers to adaptation: vulnerability and responses to heat waves in the UK. In: Adger, W.N., Lorenzoni, I., O'Brien, K.O. (Eds.), Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press, Cambridge, U.K. and New York, USA.
World Bank, 2010. World Development Report 2010: Development in a Changing Climate – Concept Note. 43. The International Bank for Reconstruction and Development. The World Bank, Washington, DC, USA.